Inverter for the 21 st Century

R. Bonn
Sandia National Laboratories
505-844-6710, rhbonn@sandia.gov

The Problem: PV inverter mean time to first failure (MTFF) is currently less than five years. This results in unreliable fielded systems and a loss of confidence in PV technology. Large volume customers of power electronics have driven power electronics development. These markets include motor drives, UPS, electric cars, inverters/converters for solar, micro-turbines, fuel cells, switching mode regulated ac and dc power supplies. The results of product evolution are benefiting all users; however there are problems unique to distributed generation that have limited the manufacturers of PV inverters to a few smaller companies. These companies have not had the required sophisticated research and reliability programs or manufacturing methods necessary to develop a mature product. Thus, the present approach to PV inverter supply has low probability of meeting DOE reliability goals.

Proposed Program: The objective is to develop a universal inverter that has a MTFF greater than ten years with a cost of less than 65 cents/watt. The program will first use a systems engineering approach to define inverter requirements. A complete set of specifications will be developed and appropriate technologies identified. The next phase of the program will produce prototype inverters. Two major program elements will be addressed during this development phase, the first will concentrate on automated assembly and the second will concentrate on the inclusion of new emerging technologies. The program will address many areas including the following.

Automated Assembly results in lowest cost, product uniformity, and improved product quality, but requires assembly of approximately 300 units/day for economic viability. In order to achieve this product volume a universal design will be employed. Thus, the inverter will be designed for use in multiple applications and for multiple technologies. The inverters required for multiple applications can use identical dc-to-ac circuitry (≈ 95% of the inverter). Designing a dc-to-dc converter module for each application will support multiple applications (example: a maximum power tracker for PV). Automated assembly will require the involvement of a sophisticated manufacturer with experience in large quantity manufacturing, ISO certification, quality programs, and systems engineering design practices.

Emerging technologies. There are three emerging technologies that can be used to greatly enhance the performance of inverters; digital signal processing (DSP), made-to-order power electronics, and new control methods such as dead-beat or repetitive control. DSP performs extremely fast signal analysis that provides inputs to low-level decisions (example: control of power bridges) and to higher-level decisions (example: control of battery charging).

The use of **DSP** will provide a reliable, low-cost method for removing dc levels from the ac output, eliminating the need for costly and bulky output transformers. Other DSP benefits include rapid response to utility transients, low harmonic distortion, and a means for switching from current source to voltage source (necessary to change from grid-tied to stand-alone operation). This approach to inverter control will result in fewer parts and longer life.

Made-to-order power electronics is a capability that results from the fact that power electronic switches, designed with software, can now cost-effectively tailor a new power module for smaller markets. With the help of DSP, the inverter can now be designed for end-of-life and can be derated as it ages. The inverter layout can also be tailored to the application, thus minimizing parasitic losses, optimizing heat transfer, and resulting in faster switching and lower heat losses.

New control methods may result in a lower switching frequency, counting on improved DSP control to ensure power quality while limiting the size and cost of the inverter magnetic components. Conversely, the trend in semiconductor switches toward lower on resistance and lower switching losses has led to higher switching frequencies and larger operating voltages and currents. This new control method could utilize the best of both worlds; lower switch losses and less frequent, lower-stress switching.

Lowered conduction losses increase efficiency and decrease heating. Every time the semiconductor is switched, transition losses occur during the turn-on/off times. To maintain acceptable losses, the turn on/off losses must be lower in devices switched at higher frequencies. Devices, such as the MOSFET and IGBT, are gated with voltage instead of current and thus require less power in the drive circuits.

Faster response can greatly reduce stresses. The integration of "smart" features on board the power device allows much faster response to over-stress conditions. This allows the power device to protect itself and therefore improves reliability of the power module. The development of on-board "smart" features in the application specific intelligent power module (ASIPM) allows for the protection of other system components. For example, overheating of a transformer or battery can be avoided.

Power Electronics Building Block (PEBB) a program, largely financed by the US Navy, is designed to advance the **integration** of power electronics.

Compliance with regulations, such as FCC Part 15 is required for grid-tied inverters. RFI filters that ensure compliance with FCC regulations are commercially available. Other passive components that are used to control the flow of energy may be manufactured in modules that are readily assembled to the laminated bus.

Magnetics are a significant portion of the initial cost and their weight and bulk have a major impact on inverter size. Bulky inverters further add to the cost of handling and installation. Currently higher frequency inverters still lower cost due to the reduced size of transformers and inductors.

Heating is a major problem with power electronics. The quickest means to reducing heat generation problems is to generate less heat by using devices with lower losses or switching schemes such as soft switching. Advanced concepts that redirect energy from dissipation in components to the output also reduce the heat dissipation needs. Sophisticated computer modeling of heat flow can improve thermal management by identifying hot spots and quantifying heat flow for various physical schemes. Additionally, improved heat dissipation is possible through better bonding, higher heat conductivity materials, and more massive paths for heat conduction.

Packaging should remove thermal energy, posses minimal electrical parasitics, maintain high mechanical reliability, reduce assembly time, and reduce cost.

Laminated DC bus bars or stripline circuit boards provide low inductance and distributed capacitance with reduced resistance while eliminating some wire connections. A major source of stress to the power-switching device is voltage overshoot that results from the interruption of current through an inductance. Configuring the power switches as components on a stripline or a laminated bus dramatically reduces the series inductance, balances it with built-in capacitance, and thus reduces the voltage overshoot.

Wire bonds are potential failure points and contain parasitic inductances. Improved connection methods that remove the wire lead include bonding of copper posts directly to the power device. This requires significant planning in the layout so that all dimensions are compatible. The Virginia Polytechnic Institute is doing considerable work in this area of bonding techniques.

Most power electronics equipment is custom-designed and requires labor intensive manufacturing processes. These are prone to lower reliability, higher manufacturing costs, and greater performance variability. A **systems-level design** of inverters, supported by design software, can go far toward improving this situation. More designs can be standardized and configured for automated assembly. The design process should also include power utilities, applications, packaging, maintenance, and supply specialists as well as power electronics design engineers.

The Desired Product: A new inverter with <u>ten-year mean time to first failure (MTFF)</u> and with lower cost. This development will constitute a ‘leap forward’ in capability that leverages emerging technologies and best manufacturing processes to produce a new inverter for multiple technologies (PV, fuel-cell, storage, etc.) and in multiple applications (grid-tied, off-grid, and UPS). The targeted inverter size is from two to ten kilowatts.

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